RESISITANCE OF COMPACTED BITUMINOUS MIXTURES TO MOISTURE INDUCED DAMAGE
FOP FOR AASHTO T 283

02 ## Scope

Moisture susceptibility of HMA mixtures is defined as the vulnerability of the mixture to be damaged by water. As moisture is collected within the HMA mixture, it can damage the bond between the asphalt binder and the aggregates resulting in stripping. The results from this FOP are used to evaluate the stripping susceptibility of the bituminous mixtures according to Superpave specifications.

03 ## Significance

This procedure is intended to evaluate the effects of saturation and accelerated water conditioning of compacted HMA mixtures in the laboratory.

04 ## Apparatus

- Superpave Gyratory Compactor
- Equipment for preparing and compacting from the FOP for AASHTO T 312
- Vacuum chamber capable of holding 6-inch (150mm) nominal diameter specimens submerged in water
- Vacuum pump and manometer
- Distilled or de-ionized water
- Heavy-duty leak-proof plastic bags, plastic film (Saran Wrap or equivalent) and tape.
- Freezer capable of 0 ±5°F
- Water bath capable of 140 ±2°F.
- Water bath capable of 77 ±1°F.
- Apparatus capable of performing indirect tensile strength test, with a load speed of 2 inches per minute.
- Steel loading strips, 3/4 inch wide for 6-inch nominal (150mm) diameter specimens.

- Forced-draft ovens.
- Pans, 75-200 in^2, approximately 1 inch deep

05 Determination of Sample Size

Determine the theoretical maximum specific gravity (G_{mm}), of the aged design mix according to the FOP for AASHTO T 209.

Determine the mass of mixture required at design asphalt binder content for a 150mm x 95mm specimen at 7% air voids using weight/volume relationships:

- Uncorrected mass of mix = $(0.93)(G_{mm})(1679)$
- The typical factor is near 0.91 for corrected (measured) density.

Prepare a few trial specimens using the Superpave Gyratory Compactor to obtain the desired void content of 7 ± 0.5 percent. Adjust the mass of the mix by making correction to the typical factor (such as 0.91) to get to within the air void limits.

06 Sample Preparation

Prepare laboratory mixed samples in accordance with the FOP for AASHTO R 30, modified as follows:

- **Immediately** after mixing, the mixture shall be placed in a pan having a surface area of 75-100 square inches in the bottom and a depth of approximately 1 inch, and cooled at room temperature for 2 ±0.5 hours.
- Place the mixture in a 140 ±5° F oven for 16 ±1 hours for curing. (Pans should be placed on spacers to allow air circulation under the pan if the shelves are not perforated).
- Subject the cured mixture to the short-term aging procedure described in AASHTO R 30 and immediately compact the mixtures.
- If plant produced HMA is used, sample should be obtained in accordance with T 168 and reduced to testing size. Bring the

sample to compaction temperature ±5° F by careful, uniform heating in an oven immediately prior to molding.

07

- Compact at least six specimens for each test in accordance with the FOP for AASHTO T 312 to the air void content of 7 ±0.5% and a height of 95 ±5mm.
- After compacting, remove specimens from the molds and store for 24 ±3 hours at room temperature.

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- Determine the specimen diameter to the nearest 0.05 inch by averaging a minimum of two measurements taken at right angles to each other at approximately mid height of the specimen.
- Determine the specimen thickness “t” to the nearest 0.05 inch by recording four measurements at approximately quarter points on the periphery of the specimen.

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- Determine the bulk specific gravity (G_{mb}) of each of the compacted specimens in accordance with Method “A” of the FOP for AASHTO T 166. Calculate the air void content in percent (P_a) for each specimen, using the formula at the left.
- Sort specimens into subsets where the average void content of each subset is nearly equal.

$$P_a = 100\left(1 - \frac{G_{mb}}{G_{mm}}\right)$$

where:

P_a = Percentage of air voids (nearest 0.1%)
G_{mm} = maximum specific gravity (T209)
G_{mb} = Bulk specific gravity (T166)

Calculation Example 10

Bulk Specific Gravity of Compacted Specimens

Percentage of Air Voids and Sorting into Subsets

I.D. No.	Dry Mass (A)	SSD Mass	Submerged Weight	Volume (E)	Bulk Specific Gravity (G_{mb})	Theoretical Max. Sp. Gravity (G_{mm})	Percent Air Voids (P_a)
1	3619.9	3625.2	2098.5	1526.7	2.371	2.552	7.1
2	3587.5	3596.4	2076.9	1519.5	2.361	2.552	7.5
3	3603.2	3610.0	2087.1	1522.9	2.366	2.552	7.3
4	3641.2	3647.8	2116.6	1531.2	2.378	2.552	6.8
5	3594.6	3601.9	2080.7	1521.2	2.363	2.552	7.4
6	3634.3	3642.8	2113.2	1529.6	2.376	2.552	6.9
Unconditioned Subset S_1 (Specimens 1, 2, & 4)							**7.1**
Conditioned Subset S_2 (Specimens 3, 5, & 6)							**7.2**

Compacted specimens were sorted to result in average air voids being nearly equal for both the conditioned and unconditioned subsets.

Calculation Example 11

Percentage Air Voids

$$P_a = 100\left(1 - \frac{2.363}{2.552}\right) = 7.41, \text{say } 7.4\%$$

where:

G_{mb} = 2.363 (Specimen No. 5 from Table above)
G_{mm} = 2.552

12 **Preconditioning**

Precondition one of the subsets by subjecting the specimens to moisture saturation followed by a freeze-thaw cycle. **The other subset is not conditioned.** The specimens of the unconditioned subset are stored at room temperature thus allowing air-drying.

13 **Saturation of Specimens**

Vacuum saturate the conditioned subset:

- Place specimens in vacuum container over a spacer

- Fill container with distilled water until 1 inch above specimen
- Apply vacuum of 13 -67 kPa absolute pressure, (10-26 inch Hg partial pressure), for 5 -10 minutes
- Remove vacuum and leave sample in water for 5 -10 minutes
- Determine SSD mass of specimen by AASHTO T 166, Method A.

Determining Degree of Saturation

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Calculate Volume of Air Voids

Calculate the volume of air voids using the formula at the left.

(See the sample calculations below for examples)

$$V_a = \frac{P_a\ E}{100}$$

where:

V_a = volume of air voids, cm^3
P_a = air voids, percent
E = specimen volume, cm^3

Calculation Example

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Volume of Air Voids

I.D. No.	Percent Air Voids (P_a)	Specimen Volume, cm^3 (E)	Volume of Air Voids, cm^3 (V_a)
3	7.3	1522.9	111.2
5	7.4	1521.2	112.6
6	6.9	1529.6	105.5

For specimen number 5, volume of air voids is calculated as shown:

$$V_a = \frac{7.4 * 1521.2}{100} = 112.57,\ \text{say}\ 112.6\ cm^3$$

where:

P_a = 7.4% (percent air voids, see previous calculation example)
E = 1521.2 cm^3 (volume of specimen, from bulk specific gravity calculation)

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Calculate Volume of Absorbed Water

- Calculate the volume of absorbed water according to the formula at the left. The difference between the partially saturated SSD mass (grams) and the original dry mass of the unsaturated specimen represents the volume of absorbed water.

$$J' = B' - A$$

where:

J' = volume of absorbed water, cm^3
B' = SSD mass after partial saturation, g
A = original dry specimen mass, g

Calculation Example 17

Volume of Absorbed Water

I.D. No.	Original Dry Mass, grams (A)	Partially Saturated SSD Mass, grams (B')	Volume of Absorbed Water, grams (J')	Volume of Air Voids, cm^3 (V_a)	Degree of Saturation, % (S')
3	3603.2	3685.8	82.6	111.2	74.3
5	3594.6	3673.9	79.3	112.6	70.4
6	3634.3	3717.5	83.2	105.5	78.9

Data for the conditioned subset is summarized in the table above. For individual specimen number 5, calculations for volume of absorbed water and degree of saturation are as shown below:

$$J' = 3673.9 - 3594.6 = 79.3 \text{ cm}^3$$

where:

B' = 3673.9 grams (partially saturated SSD mass, AASHTO T 166, Method "A")

A = 3594.6 grams (original dry specimen mass)

$$S' = \frac{100\ J'}{V_a}$$

where:

S' = degree of saturation, %

18 **Calculate Degree of Saturation**

- The degree of saturation represents the percent of total specimen air void volume filled with water.
- Calculate degree of saturation according to the formula at the left.

Calculation Example 19

Degree of Saturation

$$S' = \frac{100 * 79.3}{112.6} \quad = \quad 70.43 \text{ say } 70.4\%$$

where:

J' = 79.3 cm^3 (from previous example)

V_a = 112.6 cm^3 (from previous example)

20 **Evaluate Degree of Saturation**

- If S' is less than 70%, repeat the saturation process using more vacuum and/or time
- If S' is more than 80%, specimen is damaged and must be discarded. Repeat the entire process using less vacuum and/or time.

.Calculation Example

Evaluate Degree of Saturation

I.D. No.	Original Dry Mass, grams (A)	Partially Saturated SSD Mass, grams (B')	Volume of Absorbed Water, grams (J')	Volume of Air Voids, cm^3 (V_a)	Degree of Saturation, % (S')
3	3603.2	3685.8	82.6	111.2	74.3
5	3594.6	3673.9	79.3	112.6	70.4
6	3634.3	3717.5	83.2	105.5	78.9

Examination of the data reveals that all specimens have been saturated to the required range of 70 to 80%; therefore, testing may continue.

21 **Freeze conditioning**

Apply the following steps on the conditioned subset:

- Cover each of the vacuum saturated specimens with a plastic film (Saran Wrap)
- Place each wrapped specimen in a plastic bag containing 10 ±0.5 mL of water and seal the bag
- Place the plastic bag containing the specimens in a freezer at a temperature of 0 ±5° F for a minimum of 16 hours

22 **Thaw Conditioning**

Immediately following the freeze cycle, the specimens are subjected to a thaw period by placing them in a hot water bath for 24 hours. The process allows the water in the specimens to thaw and permits any emulsification damage to the binder to occur at the elevated temperature of 140° F.

Thaw the specimens by the following steps:

- Remove specimens from freezer
- Place specimens in a bath containing potable water at 140 ±2° F for 24 ±1 hours. Specimens should have a minimum of 1-inch cover. Place specimens on a perforated support that will not allow them to deform during subsequent handling, but will permit free access of water
- Remove bags and plastic wrap as soon as possible
- After the 24 hours at 140° F, immediately place specimens in a water bath at 77 ±1° F for 2 hours ±10 minutes
- Ice may be needed to keep the water bath at 77° F
- Water bath should reach 77° F within 15 minutes

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Determine Indirect Tensile Strength

Place the dry unconditioned subset in heavy-duty, watertight plastic bags and immerse in a 77 ±1° F water bath for 2 hours ±10 minutes prior to testing.

Test conditioned and unconditioned subsets as follows.

- Determine the specimen thickness of the conditioned subset (t’) by recording four measurements at the approximate quarter points on the periphery

Determine the indirect tensile strength of unconditioned and conditioned specimens

- Place specimen between the steel loading strips
- Place specimen and loading strips between the bearing plates
- Apply a load along the diameter of the specimen at a constant rate of 2 inches per minute
- Measure the maximum load, lb_f

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- Calculate the indirect tensile strength of each specimen in the unconditioned subset (S_1) according to the formula at the left.
- Calculate the indirect tensile strength of each specimen in the conditioned subset (S_2) according to the formula at the left, substituting the value of t’ for specimen thickness.

$$S_t = \frac{2\,P}{\pi\,t\,D}$$

where:

S_t = indirect tensile strength, psi
P = maximum load, lbf
t = specimen thickness, inch
D = specimen diameter, inch (nearest 0.05”)

Calculation Example 25

Indirect Tensile Strength

I.D. No.	Specimen Diameter, inch (D)	Specimen Thickness, inch (t)	Specimen Thickness, inch (t’)	Total Load, lb_f (P)	Indirect Tensile Strength (S_t)
1	5.90	3.80	-----	4190	119
2	5.90	3.65	-----	4230	125
4	5.90	3.85	-----	5105	143
				Average, Subset 1 (Unconditioned)	**129**
3	5.90	3.75	3.80	3980	113
5	5.90	3.70	3.75	3540	102
6	5.90	3.80	3.80	3840	109
				Average, Subset 2 (Conditioned)	**108**

For specimen number 5, indirect tensile strength (S_t) is calculated as follows:

$$S_t = \frac{2 * 3540}{3.14 * 3.75 * 5.90} = 101.9, \text{ say } 102 \text{ psi}$$

where:

P = 3540 lb_f (maximum load at failure)
B = 3.14
t’ = 3.75 inch (average of four measurements along periphery)
D = 5.90 inch (average of two measurements, mid height, right angle to each other)

Note: For the conditioned subset, values for S_t are calculated using t’ for specimen thickness

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$$TSR = \frac{S_2}{S_1}$$

where:

TSR = Tensile Strength Ratio
S_1 = average tensile strength, unconditioned subset
S_2 = average tensile strength, conditioned subset

Tensile Strength Ratio

- The moisture sensitivity of HMA mixtures is determined as a ratio of the tensile strength of the conditioned specimens divided by the tensile strength of the unconditioned specimens.
- Calculate the tensile strength ratio using the average indirect tensile strength of each subset, according to the formula at the left.
- For Superpave compliance, the TSR must be 0.80 or higher.

Calculation Example 27

Tensile Strength Ratio

Using the data from calculation of the Indirect Tensile Strength shown previously, calculate the Tensile Strength Ratio (TSR) as shown below:

$$\text{TSR} = \frac{108}{129} = 0.837,\ \text{say}\ \ 0.84$$

where:

TSR = Tensile Strength Ratio
S_1 = 129 psi (average tensile strength of unconditioned subset)
S_2 = 108 psi (average tensile strength of conditioned subset)

28 Estimate Moisture Damage

- After recording the maximum stress for a given specimen, continue loading until a vertical crack appears. Remove the specimen from the machine and pry apart at the crack.
- Inspect the interior surface for evidence of cracked or broken aggregate; visually estimate the approximate degree of moisture damage on a scale from “0” to “5” (with 5 being the most stripped) and record the observations on the report.

29 Report

- Report on standard agency forms
- Number of specimens in each subset
- Average air voids in each subset
- Average degree of saturation of the conditioned subset
- Tensile strength of each specimen
- Tensile strength ratio
- Degree of stripping “0” to “5”
- Results of observation of cracked or broken aggregate

Tips!

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- It is necessary to accurately measure specimen dimensions
- Compact trial specimens to determine needed proportions for achieving 7% air voids
- Remember to leave the specimens in the vacuum chamber for an additional 5 to 10 minutes after removal of vacuum
- Keep unconditioned subset at room temperature, then seal in water-tight bag and submerge in 77° F water bath for 2 hours prior to test
- Don’t forget the supports under the specimens during the hot-water conditioning

Sample Report

Project ____

Additive ____________________________ Amount ____________

Compaction Method ______________________ Effort ____________

Date Tested _______________ By __________________________

Sample Identification		1	2	3	4	5	6
Diameter, in.	D	5.90	5.90	5.90	5.90	5.90	5.90
Thickness in.	t	3.80	3.65	3.75	3.85	3.70	3.85
Dry Mass in Air, g	A	3619.9	3587.5	3603.2	3641.2	3594.6	3634.3
SSD Mass, g	B	3625.2	3596.4	3610.0	3647.8	3601.9	3642.8
Weight in Water, g	C	2098.5	2076.9	2087.1	2116.6	2080.7	2113.2
Volume (B – C), cc	E	1526.7	1519.5	1522.9	1531.2	1521.2	1529.6
Bulk Specific Gravity (A/E)	G_{mb}	2.371	2.361	2.366	2.378	2.363	2.376
Maximum Specific Gravity	G_{mm}	2.552	2.552	2.552	2.552	2.552	2.552
%Air Voids [$100(G_{mm} - G_{mb})/G_{mm}$]	P_a	7.1	7.5	7.3	6.8	7.4	6.9
Volume of Air Voids (P_a E/100), cc	V_a	108.4	114.0	111.2	104.1	112.6	105.5
Load, lb_f	P	4190	4230	3980	5105	3540	3840
Saturated _____ min @ _____ psi, or _____ in Hg							
Thickness, in.	t’	-----	-----	3.80	-----	3.75	3.80
SSD Mass, g	B’	-----	-----	3685.8	-----	3673.9	3717.5
Vol. of Absorbed Water (B’ – A), cc	J’	-----	-----	82.6	-----	79.3	83.2
% Saturation (100 J’/V_a)	S’	-----	-----	74.3	-----	70.4	78.9
Dry Strength (2 P/B t D), psi	S_t	119	125	-----	143	-----	-----
Average Dry Strength, psi	S_1	129					
Average Air Voids S_1, %		7.1					
Wet Strength (2 P/B t’ D), psi	S_t	-----	-----	113	-----	102	109
Average Wet Strength, psi	S_2	108					
Average Air Voids S_2, %		7.2					
Average Saturation S_2, %		74.5					
Visual Moisture Damage (0 to 5)		-----	-----	1	-----	2	1
Cracked/Broken Aggregate							
TSR (S_2/S_1)		**0.84**					

REVIEW QUESTIONS

1. What is this procedure intended to evaluate?

2. Describe the method of compaction for this procedure. To what void content must specimens be compacted?

3. How many specimens are needed for this test?

4. How are they sorted after compaction? How would you sort specimens that have percent air voids (P_a) of 7.2, 7.3, 6.8, 6.7, 7.5, 7.0?

5. Describe thaw conditioning in detail.

6. How many freeze cycles is the unconditioned subset subjected to? The conditioned subset?

7. Given the following, calculate the Tensile Strength Ratio. Average diameter of specimens = 149.9 mm; average height of specimens = 95.2 mm; average strength of unconditioned subset = 132 psi; average strength of conditioned subset = 98 psi. Does this meet the needed criterion for Superpave?